Online Access to Weather Satellite Imagery and Image Manipulation Software

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Abstract

Advanced Very High Resolution (AVHRR) and Geostationary Operational Environmental Satellite (GOES) imagery, received by antennas located at the University of Colorado, are made available to internet users through an online data access system. Created as a "testbed" data system for the National Aeronautics and Space Administration's (NASA's) future Earth Observing System Data and Information System (EOSDIS), this testbed provides an opportunity to test both the technical requirements of an online data system and the different ways in which the general user community would employ such a system. Initiated in Dec., 1991 the basic data system experienced 4 major evolutionary changes in response to user requests and requirements. Features added with these changes were the addition of online browse, user subsetting, and dynamic image processing/navigation. Over its lifetime the system has grown to a maximum of over 2,500 registered users and after losing many of these users due to hardware changes, the system is once again growing with its own independent mass storage system.

Introduction

After attending many meetings on how the EOSDIS should be organized and deployed three of the authors (Emery, Dozier and Rotar) decided to build a "testbed" data system to explore many of the concepts planned for EOSDIS. There is in general a wide-spread interest in having access to digital AVHRR and GOES data so we decided to use the direct readout antennas, operated at the University of Colorado, to provide data for an online testbed data system. The primary goal of this testbed system was to explore how users would respond to having access to online satellite data as a guide to the future development of EOSDIS. Originally only AVHRR data were available on the testbed data system but later development of the system added GOES imagery as well.

In this paper we will discuss the history of this testbed data system detailing the evolutionary changes in the system carried out to satisfy user needs. User statistics will be presented to show how people use such a system and what features serve best the general user community. We will discuss the major system changes and the implications of these changes for the operation of the system. Experience with the people aspects of such prototype testbeds will be very useful in designing and building systems like the EOSDIS.

Other Online Satellite Data Delivery Systems

The EOSDIS Testbed is not the first system to offer online access to digital AVHRR imagery. Earlier systems such as SSABLE (Simpson and Harkins, 1993) and the Geographic Land Information System (GLIS) of the EROS Data Center (EDC) in Sioux Falls, South Dakota (Oleson, 1992) have supplied at least browse and order capabilities over the network. There are many significant differences between both of these systems and the EOSDIS Testbed. First these systems required a user subscription since there were charges for all data delivered. Second these systems allowed the user to search and order over the network but data were generally delivered on tape. The Testbed provided not only the search and order capabilities over the network but also all data were delivered via the net. It also supplied processing software as well as images. Later the Testbed supplied an online service for real time subsetting of the AVHRR images.

A recent development is the Satellite Active Archive (SAA) of the National Oceanic and Atmospheric Administration (NOAA) National Environmental Satelliteand Data Information Service (NESDIS). This system is expected to eventually provide online search and delivery access to 3 years of Global Area Coverage AVHRR data starting from the present and going backwards. The SAA uses the GLIS interface to allow users to browse the data available and for relatively "small" orders (a few megabytes) the data can be delivered over the network at no cost to

the user. Any larger orders that must be downloaded to tape and then delivered to the user will have a cost associated with them which is standard NOAA/NESDIS policy.

All of these systems employ both alpha numeric interfaces and graphical user interfaces (GUI's) for the users to first search and then order data from the system. One big difference between all of these other system and the present incarnation of the EOSDIS Testbed is that all of these other systems allow the user to browse and then order a specific portion or "tile" of the overall AVHRR image while the Testbed displays a browse which includes the entire AVHRR overpass and allows the user to define that portion of the image that will be dynamically selected and subset to then be processed and delivered to the user. Actually the delivery places the processed image portion (with other associated information like overlay maps, elevations, etc.) on an FTP (file transfer protocol) site on the data system. The user has 3 days to collect the data before it is "scrubbed" off of the disk. This dynamic subsetting feature makes it possible to ship much smaller images over the network and takes best advantage of the processing speeds of the modern workstations operating the data system.

Another distinguishing feature of the EOSDIS Testbed system is that it has evolved in response to requests and input from users. The goal of this system was not to charge users for access to data but rather to learn how users would best use such a system that provided free-access. Thus suggestions and requests from users shaped the future implementation of the system. As will be seen other changes were instituted in response to institutional restrictions and practical hardware limitations.

The Initial EOSDIS Testbed System

Starting from nothing it was first thought to create a system that would make available a fixed size AVHRR image centered on the receiving site in Boulder, Colorado. Thus an 8 state region surrounding Colorado was extracted from the daily AVHRR overpass, processed to retain the 1 km resolution of the direct readout AVHRR data and placed on the data system storage which at this point was the mass store at NCAR. The processing amounted to AVHRR image navigation using the techniques discussed in Rosborough et al., (1994) and Baldwin and Emery, (1995). In addition the infrared channel images were calibrated using the technique reviewed in Baldwin and Emery, (1994). All five processed AVHRR channel images were then placed on the NCAR mass store to be accessed by the outside public.

At this point the Testbed used a simple alpha-numeric interface that listed the image files on the data system. Each filename contained the satellite name, the date, time and appropriate AVHRR channel. Users

could not view the images but rather had to order the images, pull them over the network and display them locally. Even with this limited capability many users ordered all available images and then viewed them locally. To do this users first had to contact the data system manager (Tim Kelley), set up a login (our main goal was to keep track of what people did which required the login), connect to the system, order the images and then log into our FTP site to find the images ordered. These images were identified with the image filename under a directory with the user's email ID. This aspect of the data system is one that has not changed over the life of the system and users today still retrieve their files which are identified by their extension.

These original 8-state images were relatively small (640 X 655 pixels) resulting in network file transfer volumes that were quite modest. After start-up we soon realized that many potential users did not have access to some of the basic tools needed to work with these digital AVHRR images. We then made available over the data system our processing software to manipulate and view the AVHRR images. The first problem was simple image display so we put on the data system both our SHO display program written for most UNIX workstations and our Imagic program which is image display for all color Macintosh computers. In the early days of the Testbed a lot of the user access was for collecting these programs. Electronic mail (email) requests from various users made it clear that they were actively using these programs to work with the images they were acquiring over the network.

One interesting development was when one user asked if we had PC display software. When we replied that we did not the user volunteered a freeware display program for the PC which we then made available over the data system.

One of the first user requirements that we acted upon was a persistent request to be able to view the images before ordering them. This would make it possible for the user to determine if the data were of interest. Did they contain the clouds of interest or were the images sufficiently cloud-free so that the users could see the ground targets. Our first response was to create smaller versions of each 8-state image that could be transferred by FTP a lot quicker than the full images and then viewed locally by the users. To insure that browse images were available for both day and night, only channel 4 (~11.0 μm) was used to compute these highly subsampled FTP browse images.

Larger Images

The most frequent request that we received from users was to provide data from areas that were within our antenna reception circle

but were not included on the 8-state images loaded on the data system. Users wanted Texas, parts of California, the west coast, Oklahoma, etc. In response we increased the size of the images on the system. This increased the image size to about 4 megabytes which not only stressed the storage of the Testbed system but also placed high demands on the network transfer of these larger images. Also the system navigation requirements increased to process all of these larger images. The storage requirements on the NCAR mass store system increased by a factor of about 5.

The system configuration at this time is shown here in Fig. 1 which shows the connection between the NCAR mass store and the Decstation 5000/100 which acted as the system computer and interface.

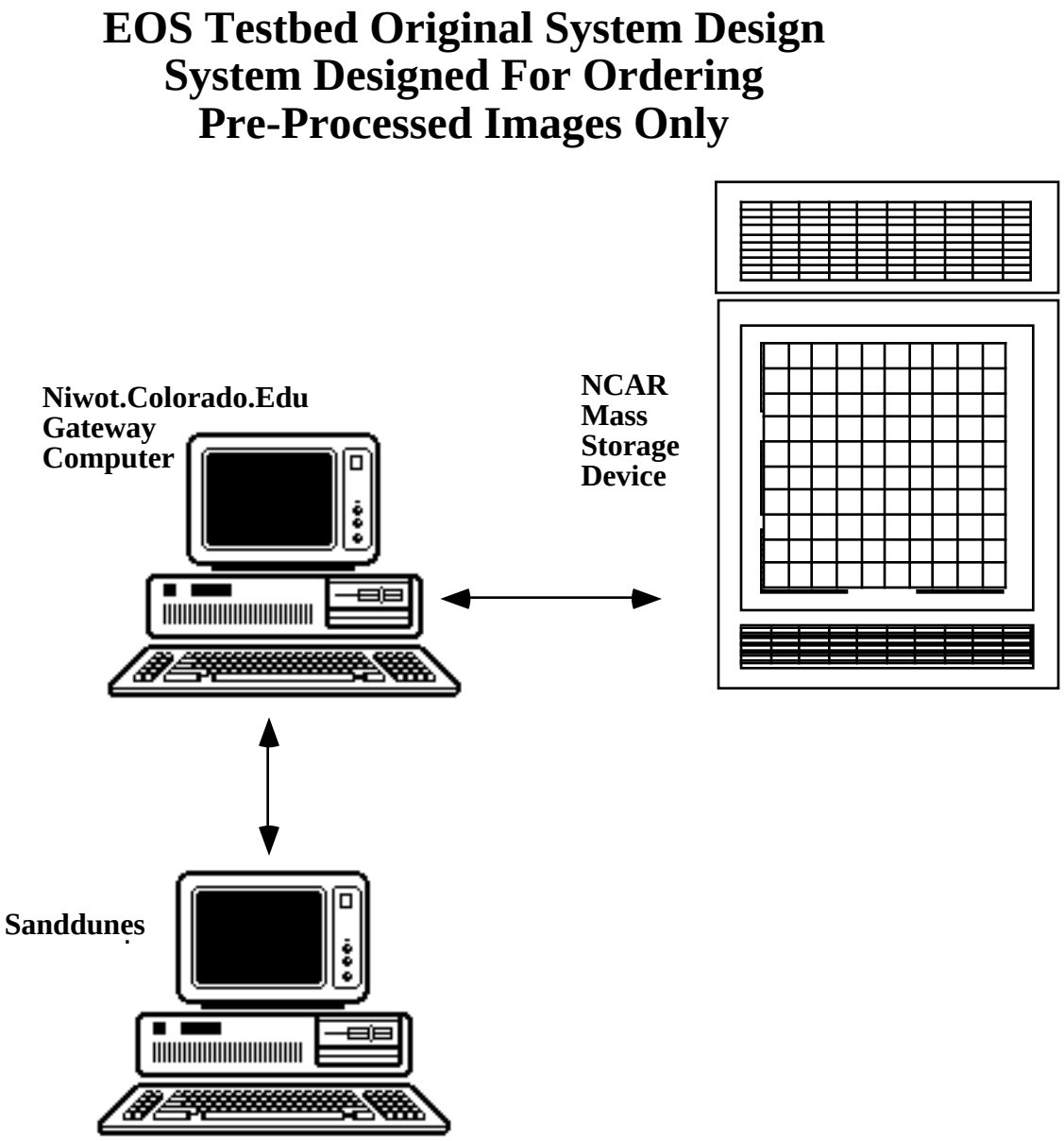

Fig. 1

This Sanddunes workstation had its own local SCSI disk which acted as the storage for the small browse images and the FTP site for the system output. Back then the users only had 24 hours to retrieve their ordered images. This system made relatively minimal demands on the NCAR system and for a while the system worked quite well.

Online Browse

All of the FTP requirements on the system were quite demanding and it was clear that if we could somehow develop an online browse capability we could save considerably on the need for data to be shipped over the network. Since most users were running some type of x-windows environment on their computers we decided that using a client-server system we could mount the browse images which were then displayed on the user's workstation/computer. This worked well with UNIX machines and on MAC's and PC's running some type of x-windows emulator. Each browse image included land boundaries, rivers, lakes and state boundaries to ease identification. After the introduction of this online browse feature there was a noticeable drop in the number of images ordered by the users.

Image Subsetting

After going to the larger images and instituting online browse users began to ask for the ability to subset these large images that they were getting over the network. It became clear that what users really wanted was only a small part of each image and not the whole thing. Thus we were stressing our processing system and the network to provide the users with a lot of image data that they did not want. In fact the most frequent request was for some software that could easily extract only those image portions that the users were interested in. We realized that the ideal system would be one that made it possible for the users to define online that portion of the image that they were interested in, extract, process and deliver only that part of the image. This led to the development of the "navigate" system.

The Navigate System

The big change in this evolution of the Testbed was the on-the-fly navigation of the portion of the AVHRR image requested by the user. Hence we called this system "navigate" to distinguish it from the earlier system. Both were run in parallel for a while when the navigate system was first introduced. We did not want to take away a capability that people were using for a new system even if we believed it was inherently better. We operated the older "order" system until the volume of userrequests dropped off completely.

In the navigate system the user must first go through a search procedure to define the image of interest. This step uses the same format as in earlier versions of the Testbed except we added a new feature letting the users specify U.S. or Canadian cities rather than their latitude and longitude (Fig. 2).

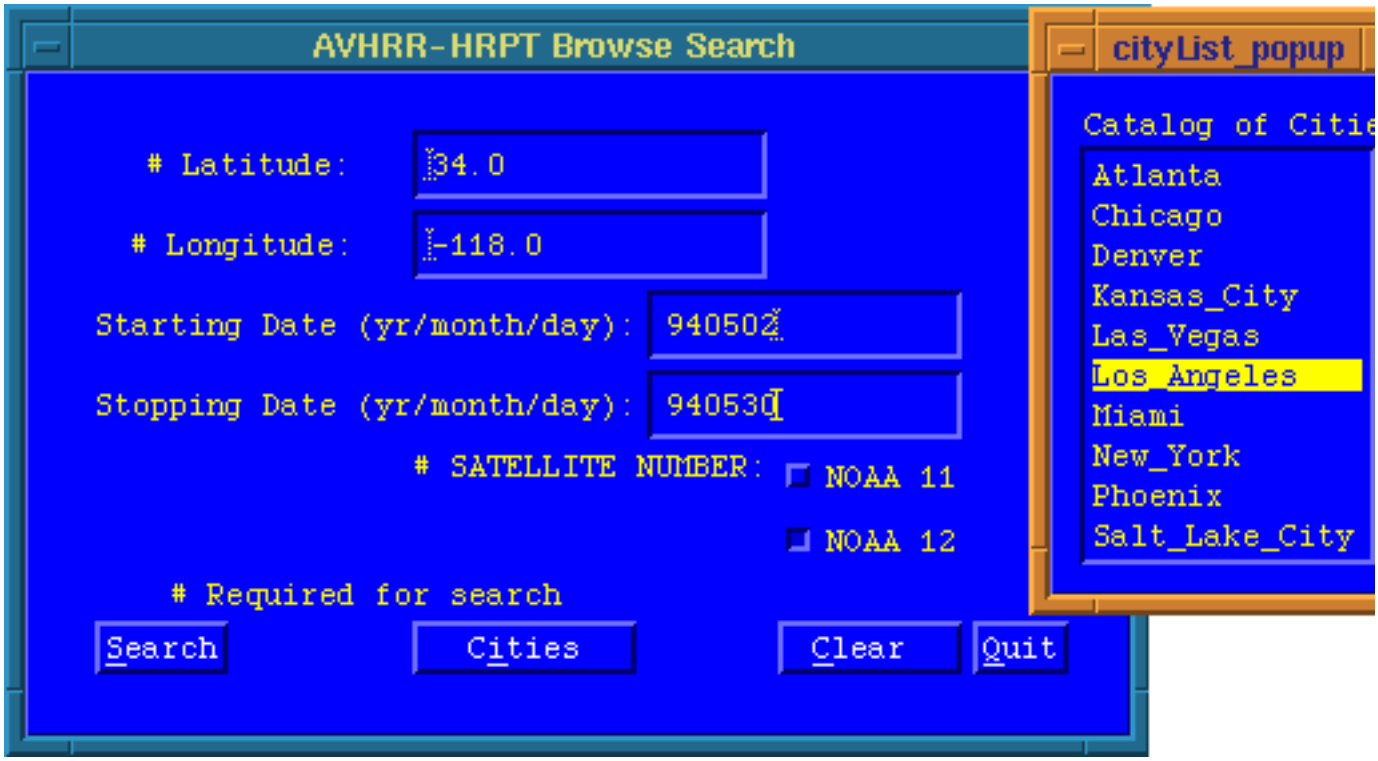

Fig. 2

The system then automatically enters the appropriate latitude and longitude. At this point the user must also specify which satellite (or satellites) they are interested in and a search period. A list of files in then returned and by high-lighting the browse version of an image of interest the user is presented with a browse image of the full AVHRR overpass (Fig. 3).

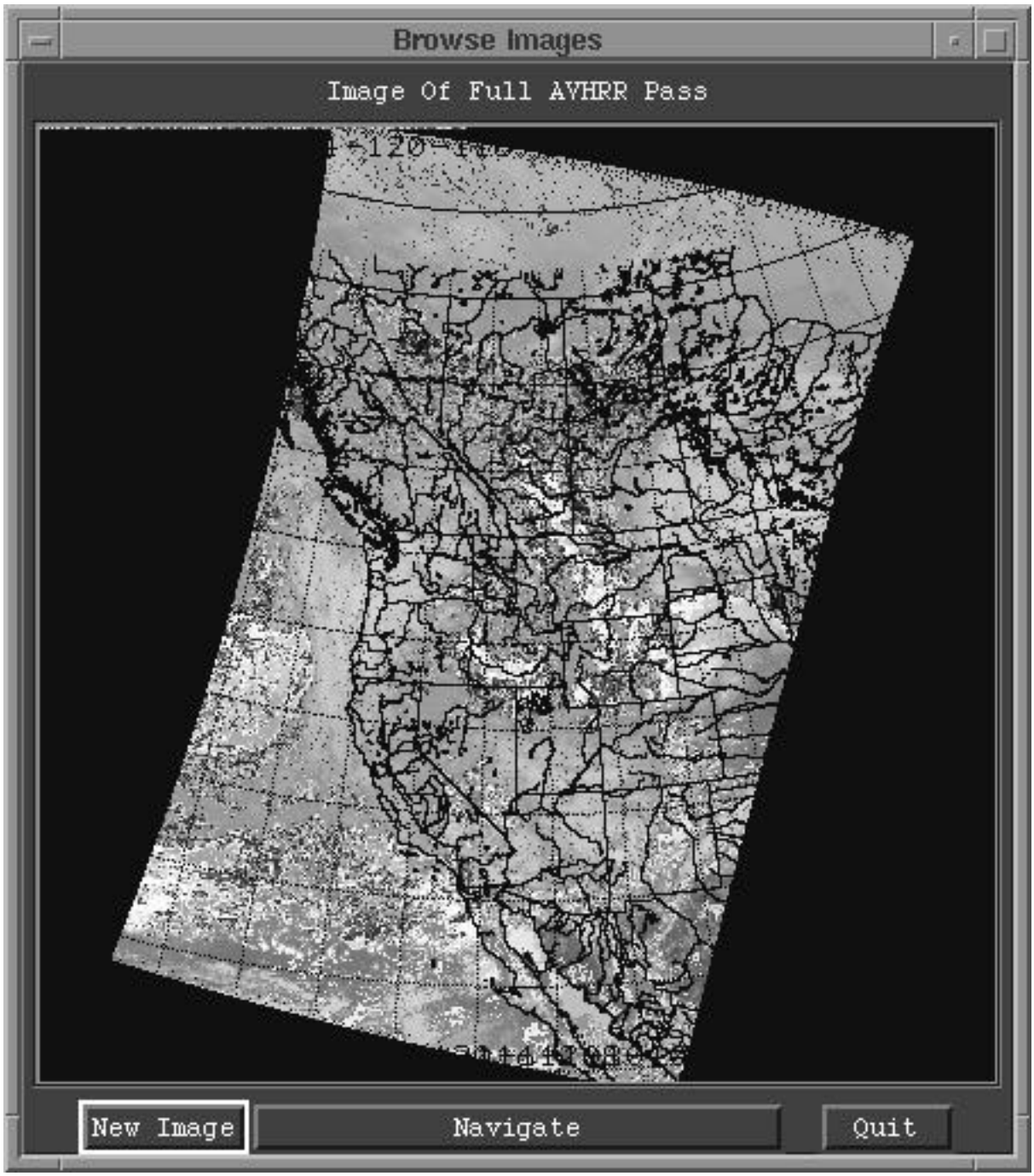

Fig 3

This full-pass browse image includes an overlay map to help the user locate regions of interest. The user can decide if an area of interest fits the analysis requirements (i.e. clouds or no clouds). If the browse suggests the image portion is worth ordering then the user brings up the "navigate" screen (Fig. 4) which gives the system ordering options.

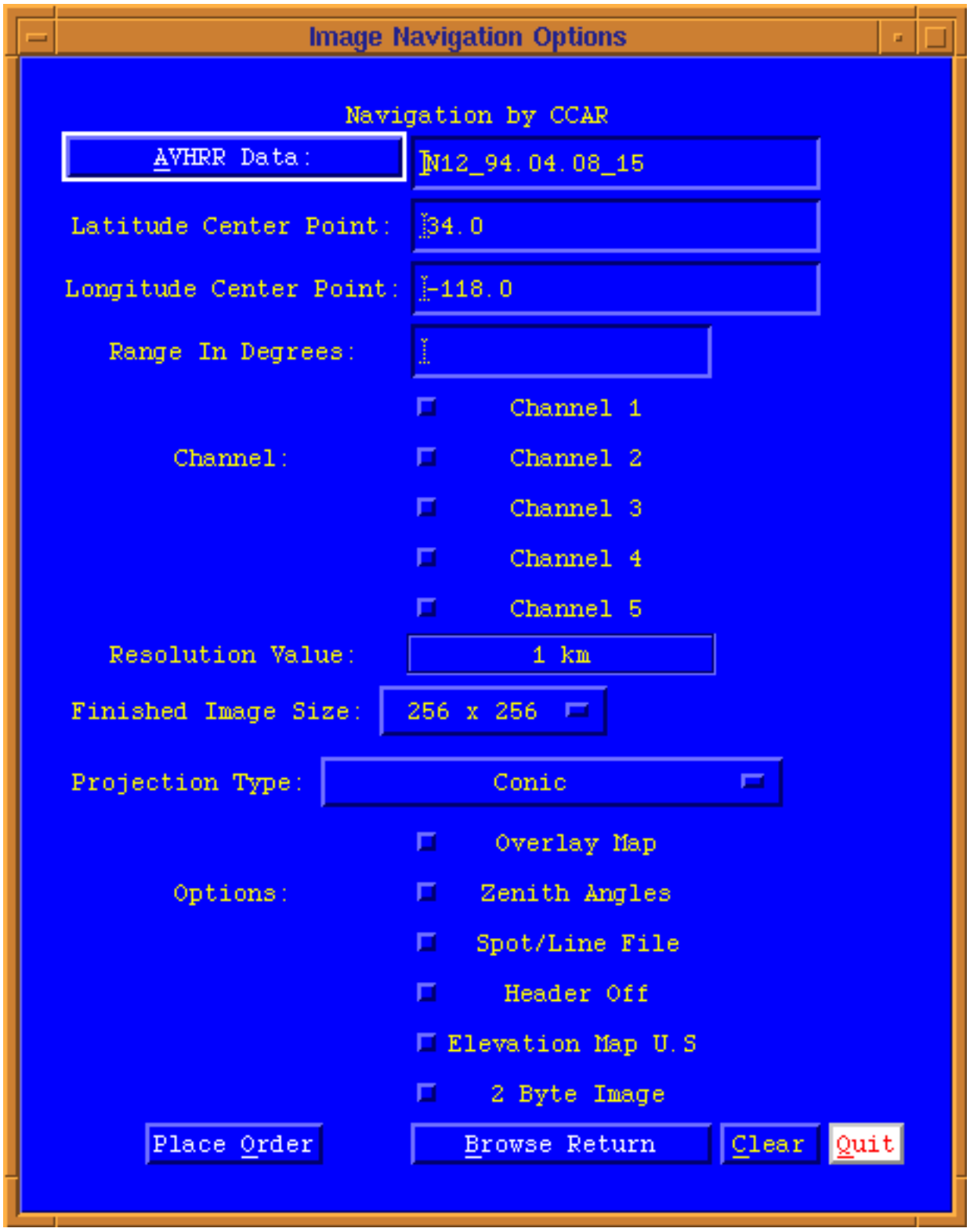

Fig. 4

The user must then choose a box size (by specifying the range) around this center. The user can then choose any or all of the 5 AVHRR channels followed by the specification of the image resolution and image size

(256, 512, or1024 squared) and the projection type. Finally the user can order some ancillary information such as an overlay map, solar zenith angles, line and pixel location, elevations for the U.S., turn off our header and order a two-byte version of the 10-bit AVHRR data.

Once the navigate order was placed the system would retrieve the raw data from the mass store, select the general portion of the image requested, navigate and calibrate the image(s) and place the results on the FTP disk for later retrieval by the user. Again the user had 24 hours to collect the digital data by FTP before it was scrubbed. An interesting consequence of this new navigate system was the fact that NCAR was concerned about the use of its computer resources so a program was written to locate the least busy computer in the IBM RS-6000 cluster at NCAR where the requested image was then navigated. Thus the system configuration appeared as shown in Fig. 5.

Navigate I Using Sanddunes, NCAR Network & Mass Storage Device

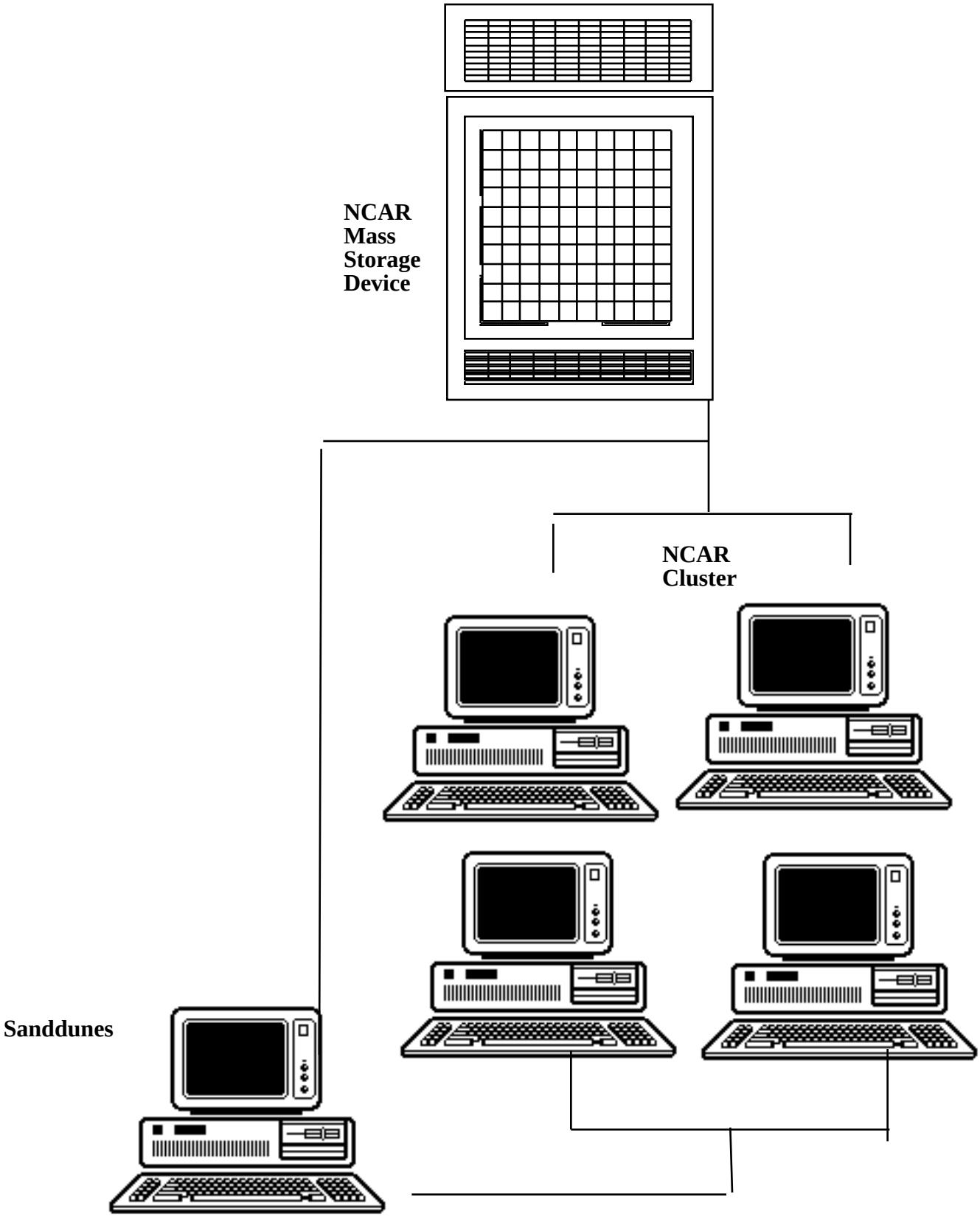

Fig. 5

Again the system worked well for a period as will later be shown when we discuss the growth of the system in terms of user logins. In fact there was some substantial user growth of the system now that it supplied what many of them had requested.

Adding GOES Imagery

Since downlink antennas for the direct readout of both AVHRR and GOES-7 imagery were in operation at CU/CCAR it was a natural extension of the Testbed to include GOES imagery in addition to AVHRR imagery. Since the visible GOES images were very large in digital volume (~ 245 MBytes every half hour) we decided to subsample the images for inclusion on the Testbed system. We subsampled both the visible and thermal infrared images (and later water vapor) down to a 22 km spatial resolution and stored the GOES images on a separate "rotating" archive. Rather than permanently store all the GOES images, as we had the AVHRR, we created a rotating archive where the GOES images were available for a week before they were erased to make room for the new GOES images being added to the system. Thus there is no long-term retrospective use of the GOES images on the Testbed system This is a compromise that was dictated by the greater GOES image volumes.

An example of the GOES browse image is displayed in Fig. 6 which is the full 22 km spatial resolution of the digital images that can be ordered by the users.

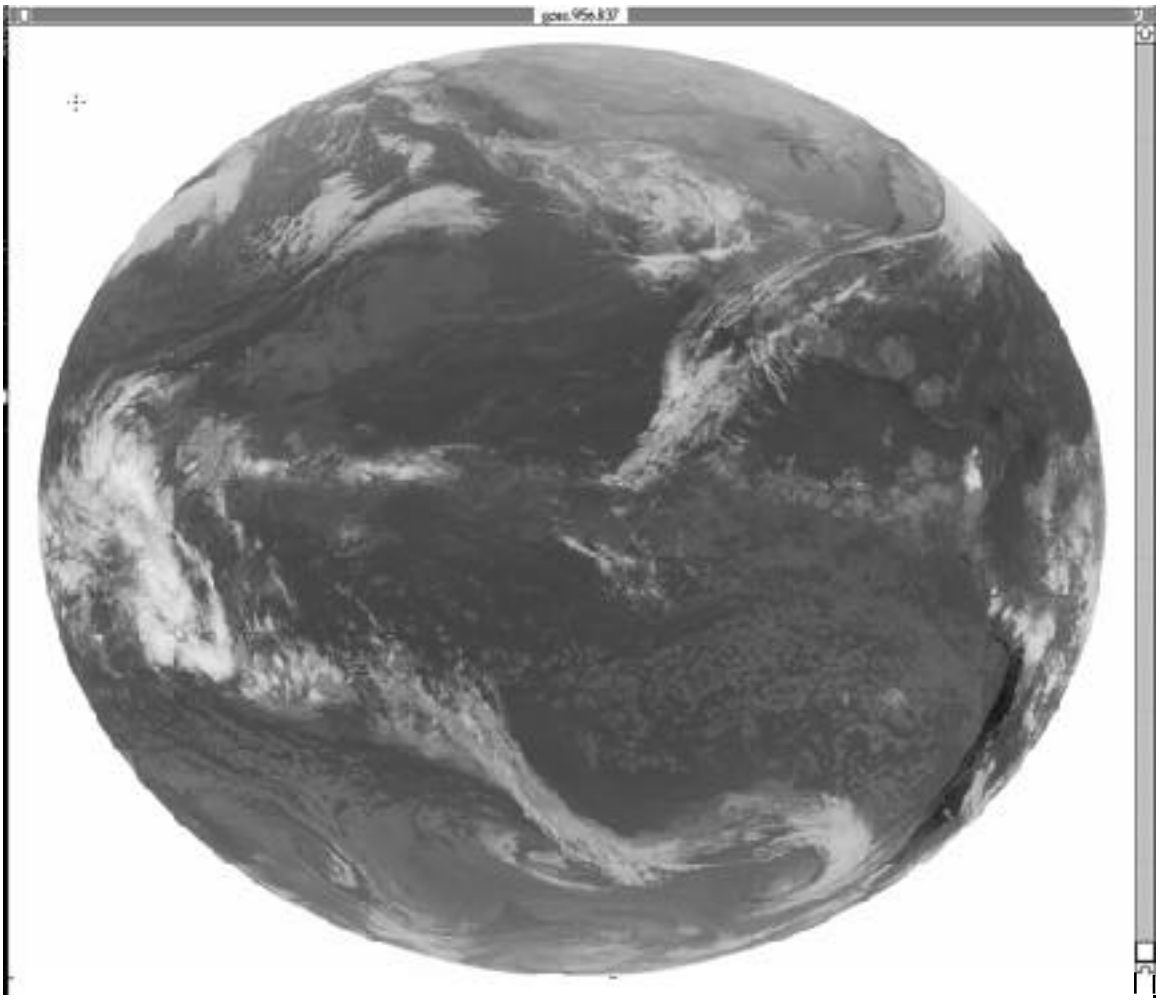

Fig. 6

Since we found that most GOES users wanted full-disc images we did not implement an online subsetting system as we had done for the AVHRR images. For a brief time we tried a system where the users could display a time sequence of GOES images as an animation but this slowed the Testbed computer down considerably and was therefore dropped. We did, however, add the GOES-7 water vapor channel as a regular 22 km subsampled product again as part of the rotating archive. As part of the new local mass store we are now archiving all of the 22 km GOES images on tape so that retrospective orders are now possible for GOES images as well as the AVHRR data. Still no GOES subsetting has been implemented.

The Growth and Evolution of the Testbed System

The Testbed opened in mid-Nov., 1991 with no users as shown here in Fig. 7. Initially the system user community grew up to about

400 monthly logins when the first browse was introduced. As mentioned earlier this reduced the images ordered through the system.

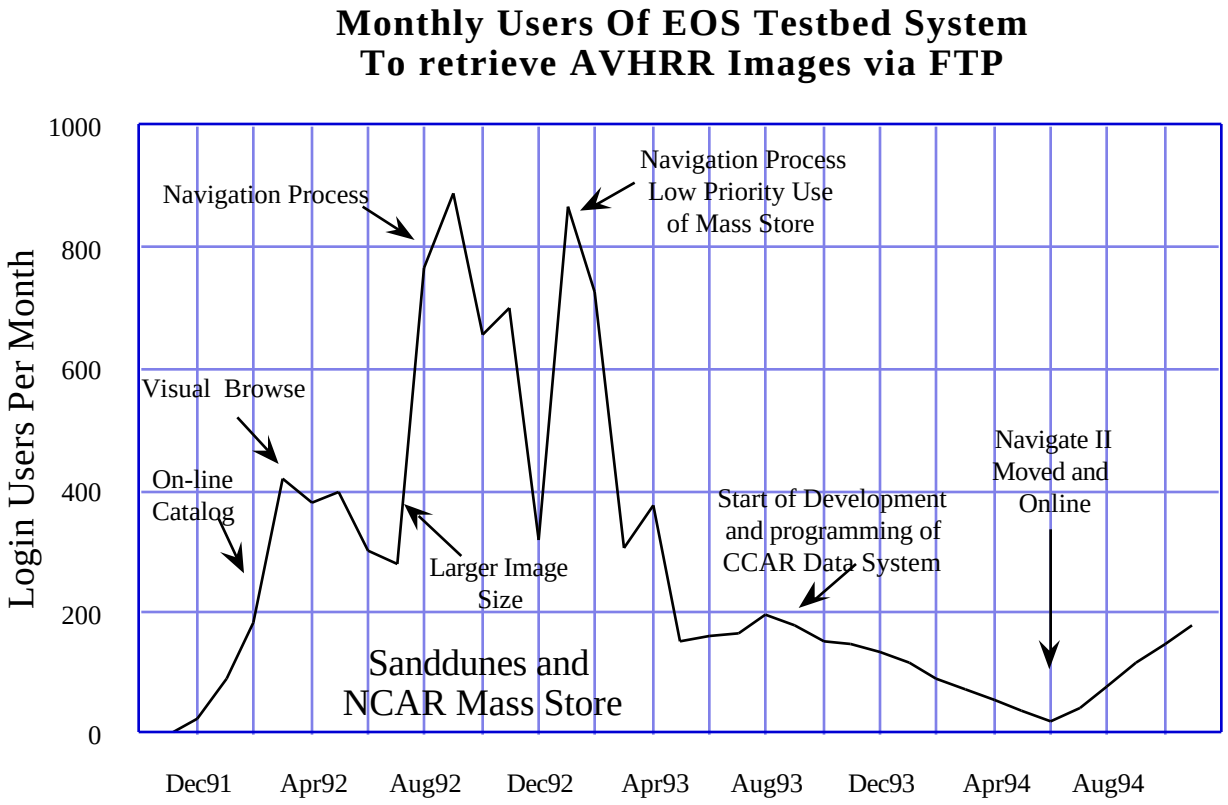

Fig. 7

This is clearly demonstrated in Fig. 8 which is the corresponding monthly transfer of AVHRR images through the system.

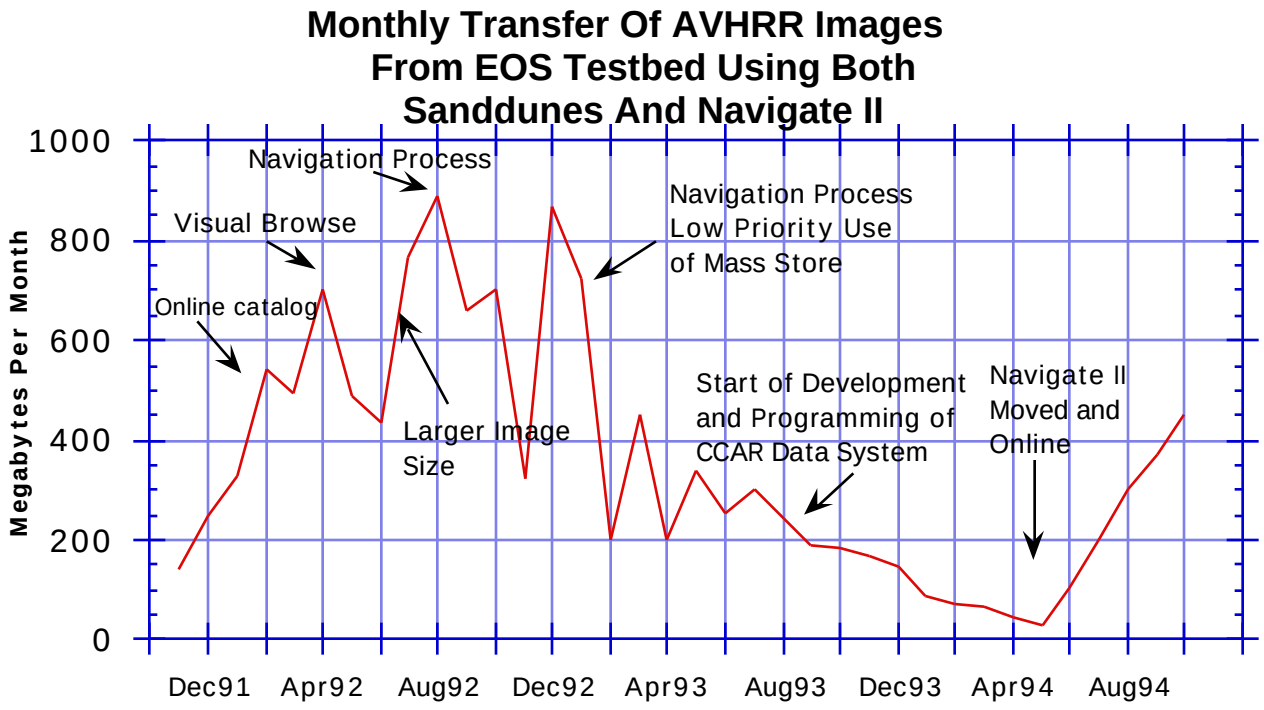

Fig. 8

Both the use of the system and the volume of use declined through the spring of 1992 starting to grow again when the larger images were introduced. Monthly system users and image volumes continued to increase up to a maximum of about 900 users per month and 800 MBytes per month in Aug. - Sept. of 1992. About this time the new navigate system was introduced which initially saw a decrease in system use both in terms of monthly logins and image transfers. Interestingly enough the image transfers increased to a maximum in Dec., 1992 (Fig. 8) which occurred in a month with a minimum of logins (Fig. 7). This means that fewer users ordered more images than in months when more users were accessing the system.

Soon after the Feb., 1993 monthly user login maximum the system use started to decline. At this time NCAR operations staff decided to decrease the priority of the data system for accessing the NCAR mass store. In spite of the savings brought in by the navigate system the EOSDIS Testbed system was starting to have a visible impact on the use of the NCAR mass store. As a consequence of this lowered priority data system users could no longer retrieve requested data files before the system would time out therefore reporting that the data were not available. This caused a very precipitous drop in data system use as shown clearly by Figs. 7 and 8. Some users were still accessing the system to collect imagery but the majority of users were no longer

satisfied with this low level of service. We decided to develop our own local mass store system to eliminate the problems with the NCAR mass store file retrieval. While continuing to operate the crippled system at NCAR we started to acquire hardware and write software to perform our own file management and automated data retrieval for a stand alone Testbed data system. Once this system was completed we now had a completely stand-alone system with a configuration as shown here in Fig. 9.

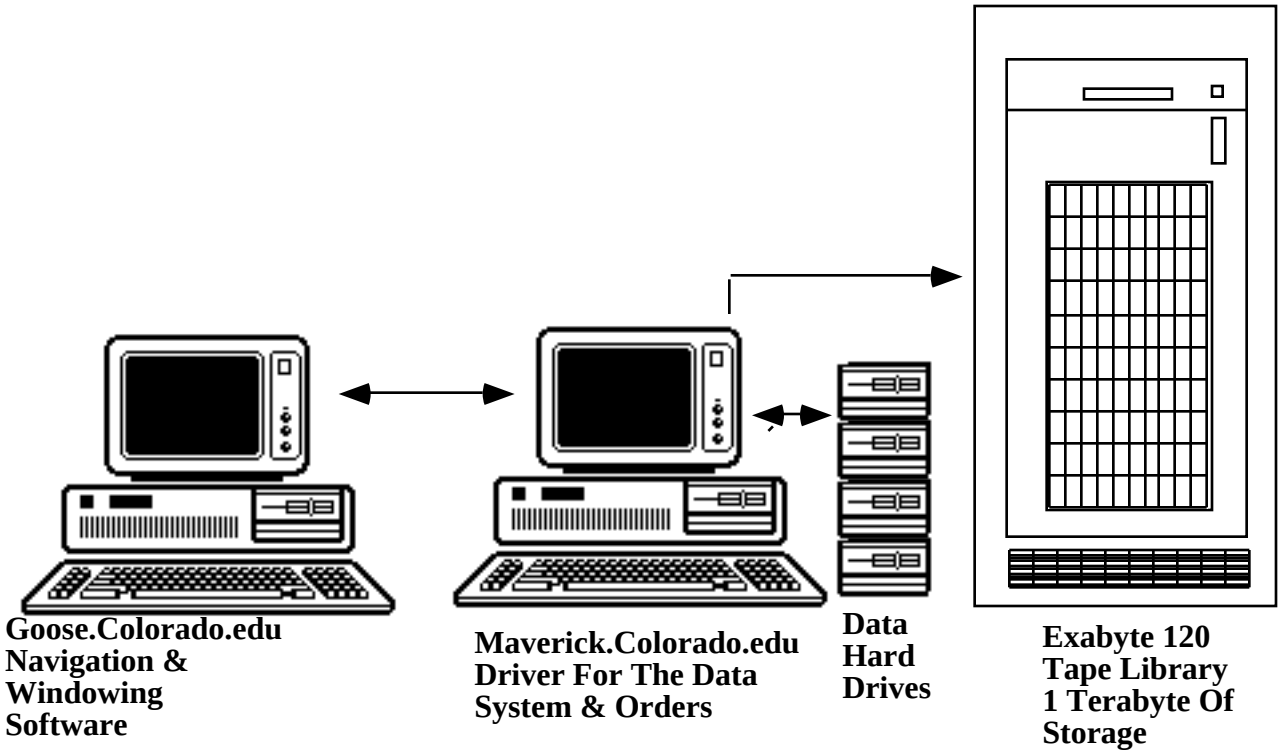

Fig. 9

Unfortunately this development took longer than the 2-3 months we had projected and the new system was not ready until the middle of 1994. At the temporal ends of Figs. 7 and 8 there is an almost linear growth of both the monthly logins and the volume of images transferred showing how the users responded to the availability of the new system. The overall growth of the user community is presented in Fig. 10.

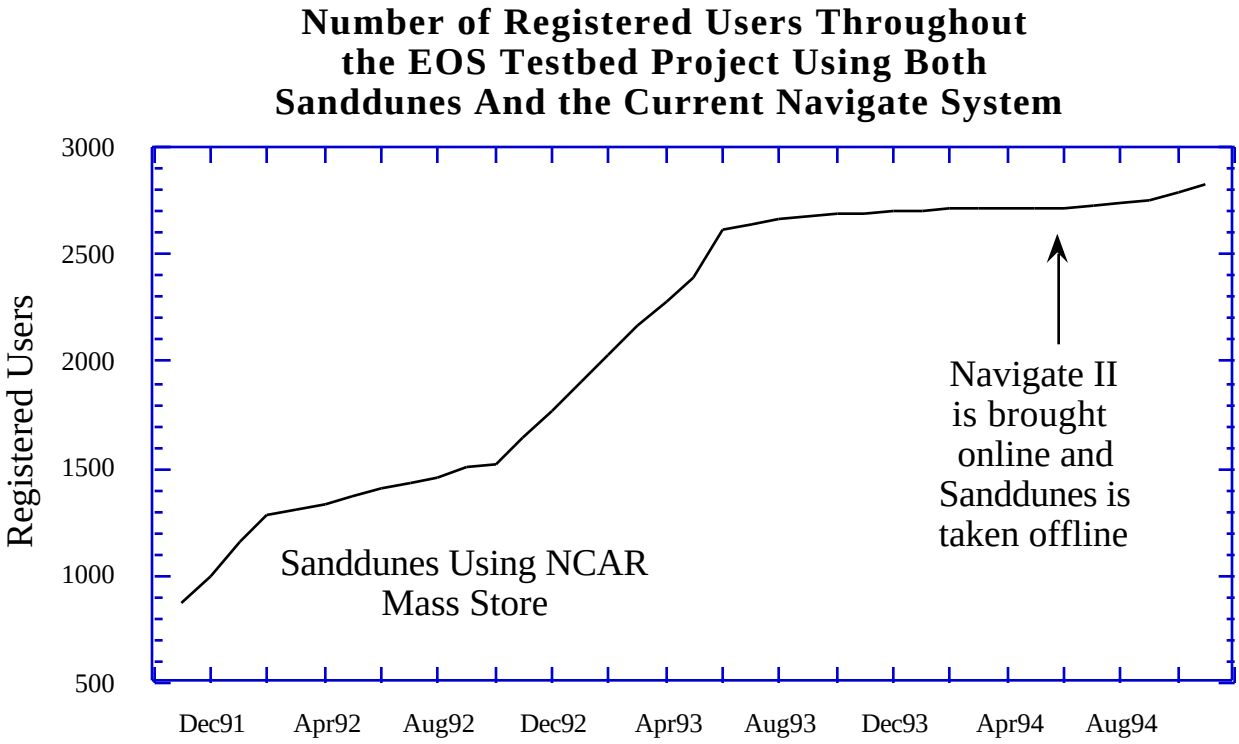

Fig. 10

Each change in the slope of the growth curve corresponds to a change in the Testbed data system. The steepest growth in the overall user community occurred with the introduction of the initial navigate system. This growth continued up to a maximum of about 2,700 users before the change with the NCAR mass store led to a cessation of this growth. Thus the upswing with Navigate II does not mean that we now have over 2,700 users but rather indicates that we have a new group starting from there. We have considered the start of the Navigate II system as a new system since we lost almost all of the past users. We have been trying to contact them again but it is a slow process even using email.

The User Community

As shown in Fig. 11 the users of the original system, called Sanddunes and located at NCAR, can be separated into a number of general groups.

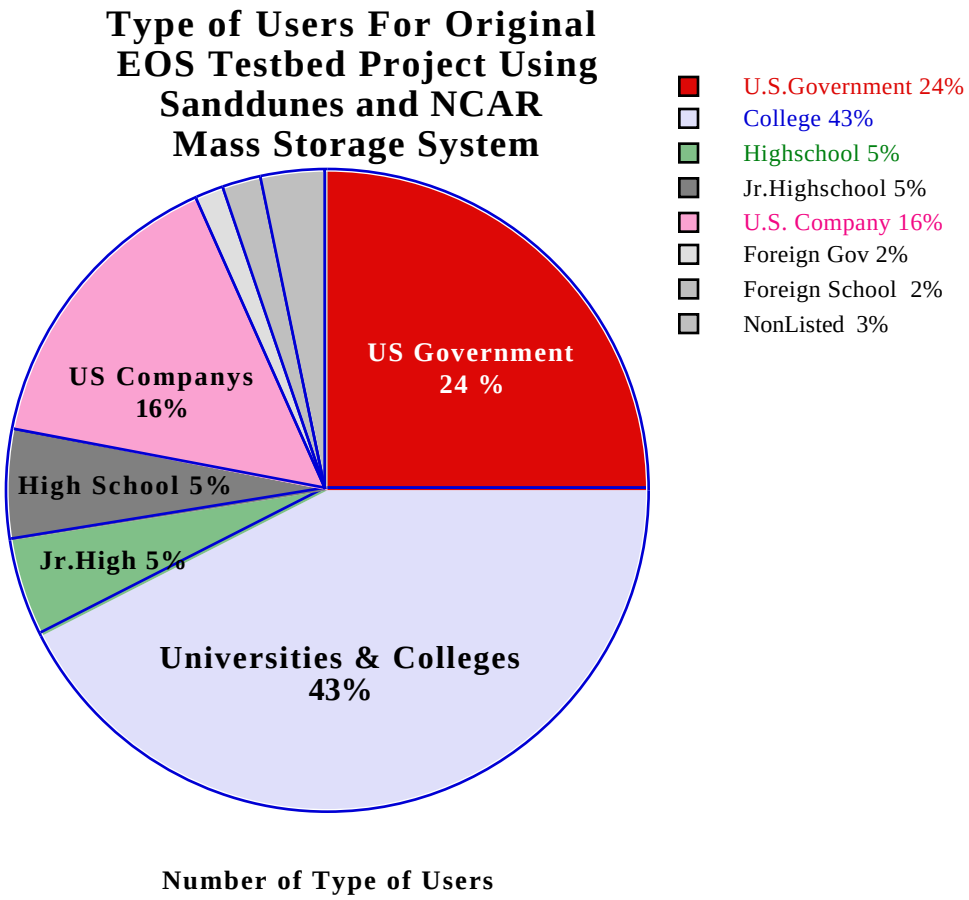

Fig. 11

The largest segment of the user community (43%) consisted of U.S. universities and colleges. This is only natural since the present state of the internet has resulted in the connection of most major colleges and universities in the U.S. Uses of these online satellite data at these academic institutions ranged from analysis in classroom situation to the individual analysis of images for a thesis topic. Surprisingly government agency users made up the second largest group (24%). These government users also included people from NOAA/NESDIS the agency that operates the satellites. Private U.S. companies comprised the next largest group (16%) and it was interesting to discover the variety of uses that people made of these online data. Oil companies would use the thermal imagery to assist them in predicting the thermal inertia in portions of the U.S. while other commercial users would augment their ground data with the satellite images.

When the system ran into data delivery problems the fastest growing user segment was secondary schools. A number of high schools and junior high schools connected to the internet were using data from

the system in classes and individually. One interesting anecdote came through questions from one junior high school student interested in printing the images. When jokingly asked (over email) by Tim Kelley if the student "was selling the images to his friends?" the reply came back "it isn't illegal is it?" The entrepreneurial spirit is alive at that junior high. The remaining users included foreign government agencies, foreign colleges and universities and finally individuals that can access the internet. This user breakdown has shifted slightly with the new system as will be discussed later.

The Stand Alone Navigate II System

The stand alone system required an independent mass storage system. We could not afford any of the expensive system such as the Storage Tek 3480 cartridge silo or the Metrum VHS cassette system. We thus purchased a 120 tape Exabyte jukebox with a generous discount from Exabyte Corp. We could not afford any of the commercially available file management software systems and therefore decided to write our own. This task was contracted to Steve Monk of C.U.'s Laboratory for Atmospheric and Space Physics (LASP). An added problem was the lack of driver software for the 120 jukebox particularly for the DEC Alpha workstations we had acquired to run the Testbed. We were forced to again write our own drivers for this system. These complications resulted in some considerable delays in being able to open the new system. A little over a year after the start of problems with the NCAR mass store we were able to open the new stand alone Navigate II Testbed system.

Fortunately our new system performed even better than expected. One real advantage of the new system was its speed in being able to process and deliver the requested images. This is demonstrated by Fig. 12 which shows the time (in minutes) per image taken to complete the processing of the AVHRR images for the different phases of the Testbed system.

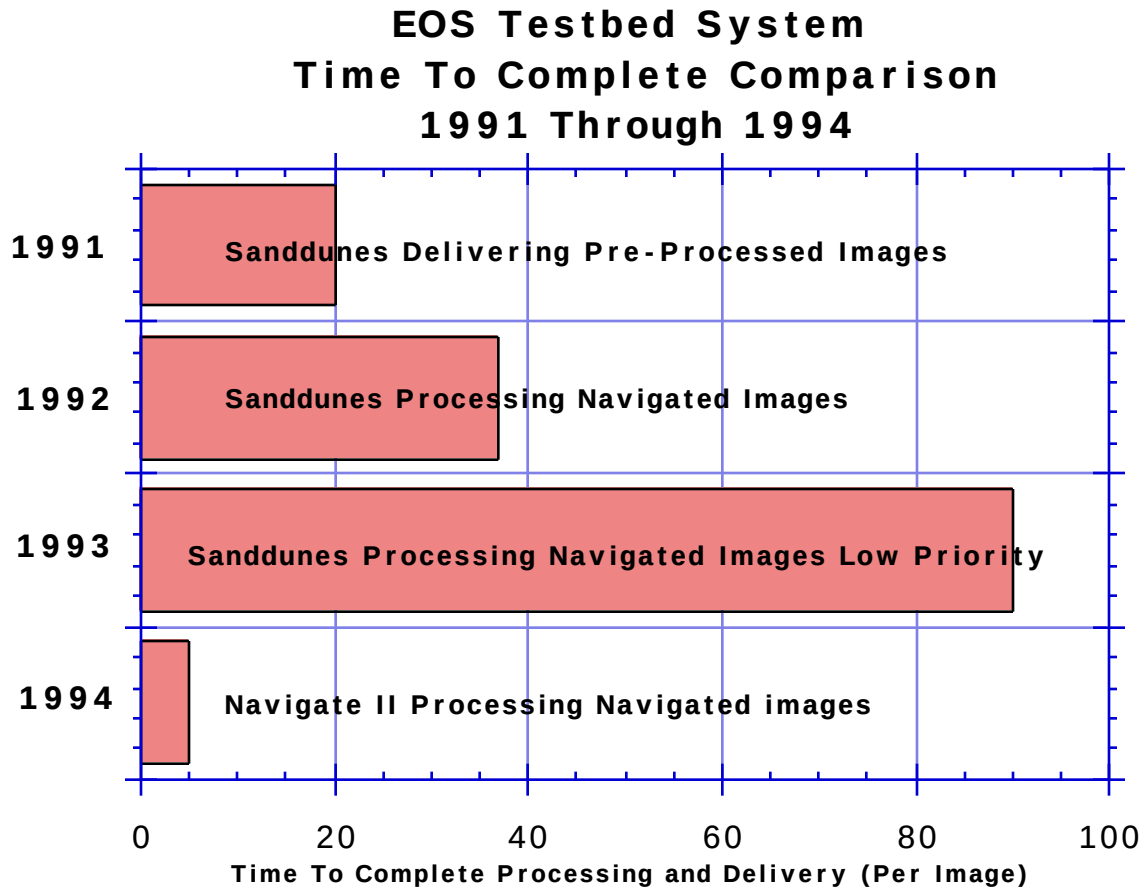

Fig. 12

The initial system took up to 20 min to retrieve and process images. The first navigate system could take up to 35 min which increased to an hour and a half after the low priority was instituted on the NCAR mass store. By comparison the average of 5 min for the Navigate II system is very fast. This time includes the file retrieval from one of the 120 Exabyte tapes, loading the file to disk, processing the image as requested by the user and storing the results on the FTP site.

The user community changed somewhat with the Navigate II system. Plotted here in Fig. 13 the number of users is significantly greater for universities and colleges (63%) and at this time there are no secondary schools using the system as yet.

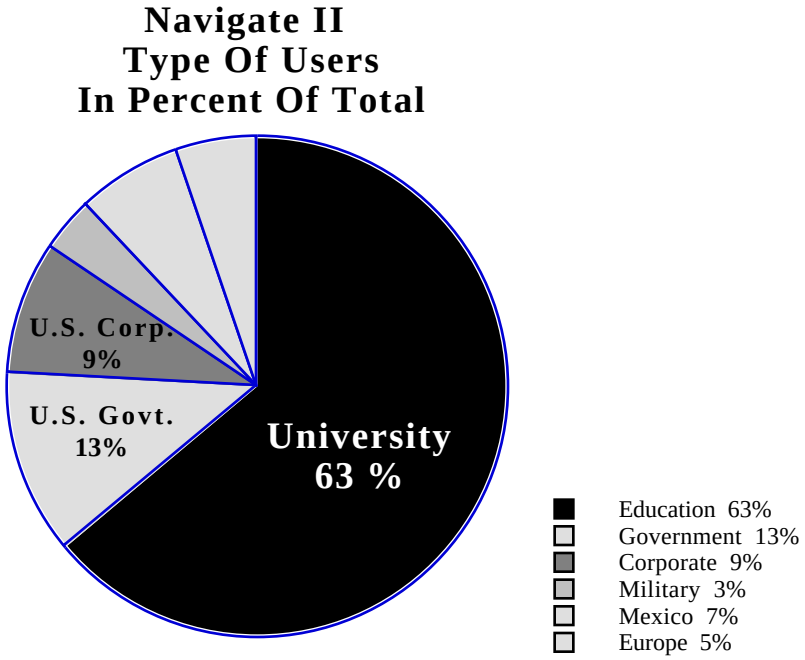

Fig. 13

It has taken a while to inform our past user community and it is likely that many of the schools do not know how to access the new system. We are now working to have not only information on the system available on the World Wide Web (WWW) but also to have the system accessible through MOSAIC and NETSCAPE.

It should be noted that Fig. 13 now refers to a substantially smaller number of users. Users now number in the few hundreds rather than in the thousands. Still we have an active number of U.S. government and industrial users. There are still European and Mexican system users and a small number of U.S. military users.

November 1993 User Statistics

The Navigate II system provides a new opportunity to map user patterns since we are now keeping more information about usage patterns. We now control all aspects of the system and can therefore track each login and order. Taking November, 1994 as a random example we can plot all of the data types ordered from the system (Fig. 14).

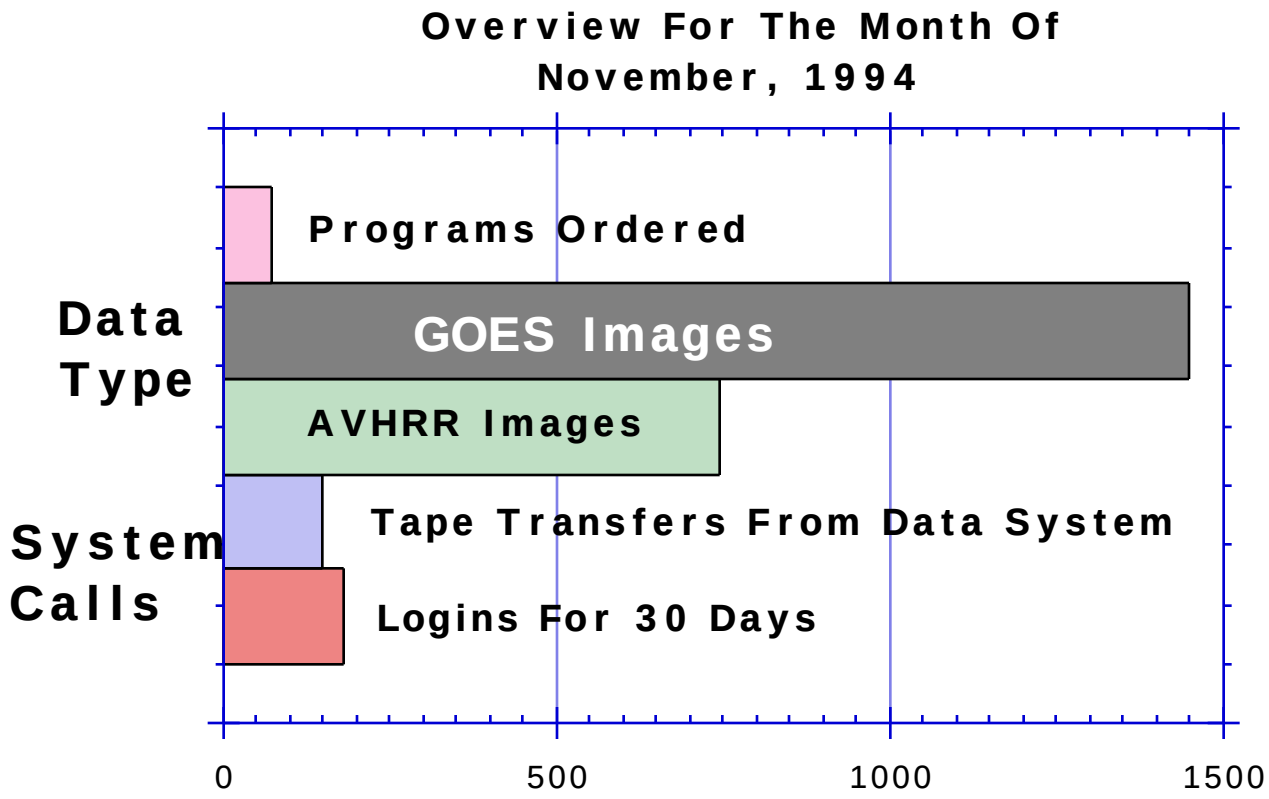

Fig. 14

It is no surprise that in terms of volume GOES-7 images make up the largest category with almost 1,500 images ordered in the month. The next largest category is AVHRR images followed by programs ordered. All of this activity was for only about 200 logins for the month and only 150 tape calls. Thus it can be concluded that users generally ordered multiple images with each logon.

The day-to-day variability of the system use is also very interesting (Fig. 15).

Daily Logins For The Month Of November 1994

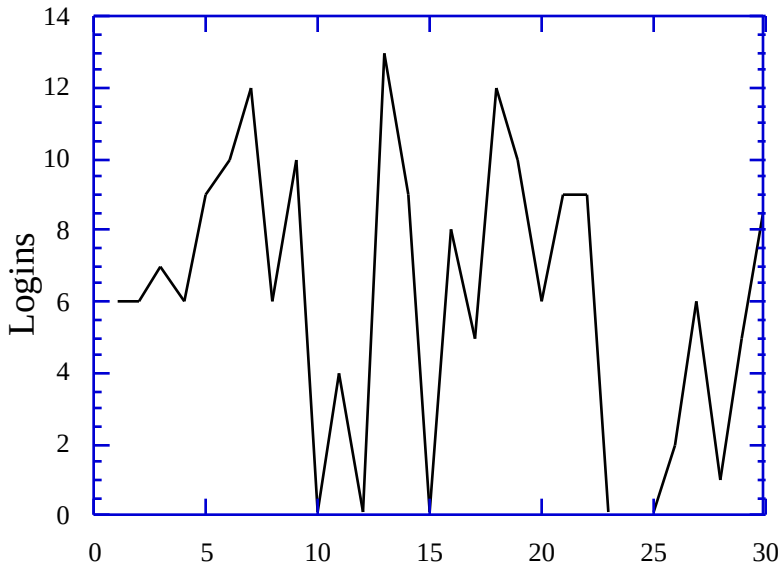

Fig. 15

We can clearly see the effect of Thanksgiving which led to a sharp drop to zero in system use. Another earlier drop in use is less easy to explain as it does not coincide with a major U.S. holiday. Turning to the question of what AVHRR images were ordered for the month we can see in Fig. 16 that most of the images requested came from 1994 or the latter part of 1993; images from 1992 were available on the system but no requests were made that month for these older images.

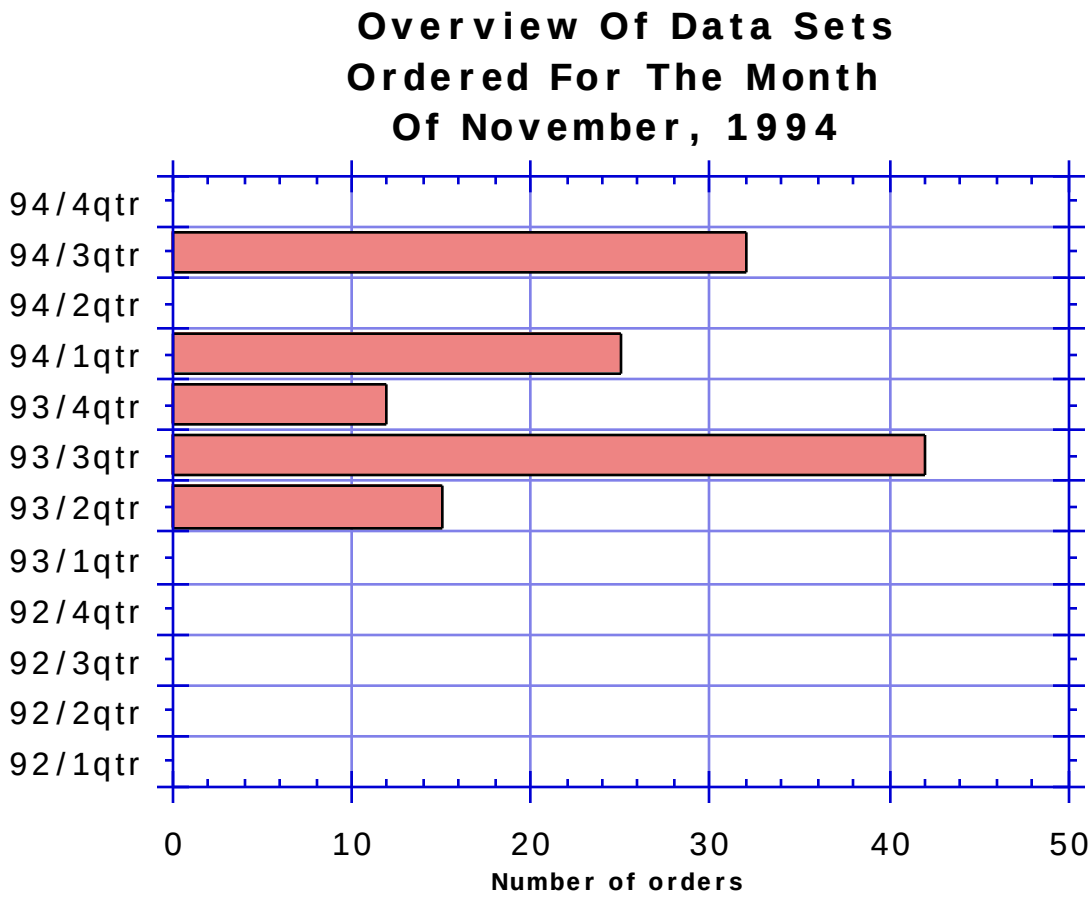

Fig. 16

There is a surprising gap in the spring of 1994 which we can't explain at this point. The data of greatest interest were the fall images from 1993. Clearly there is a lot of volatility to these numbers and it is difficult to draw any conclusions from a single month's sample.

Another very interesting piece of information is the diurnal use pattern (Fig. 17).

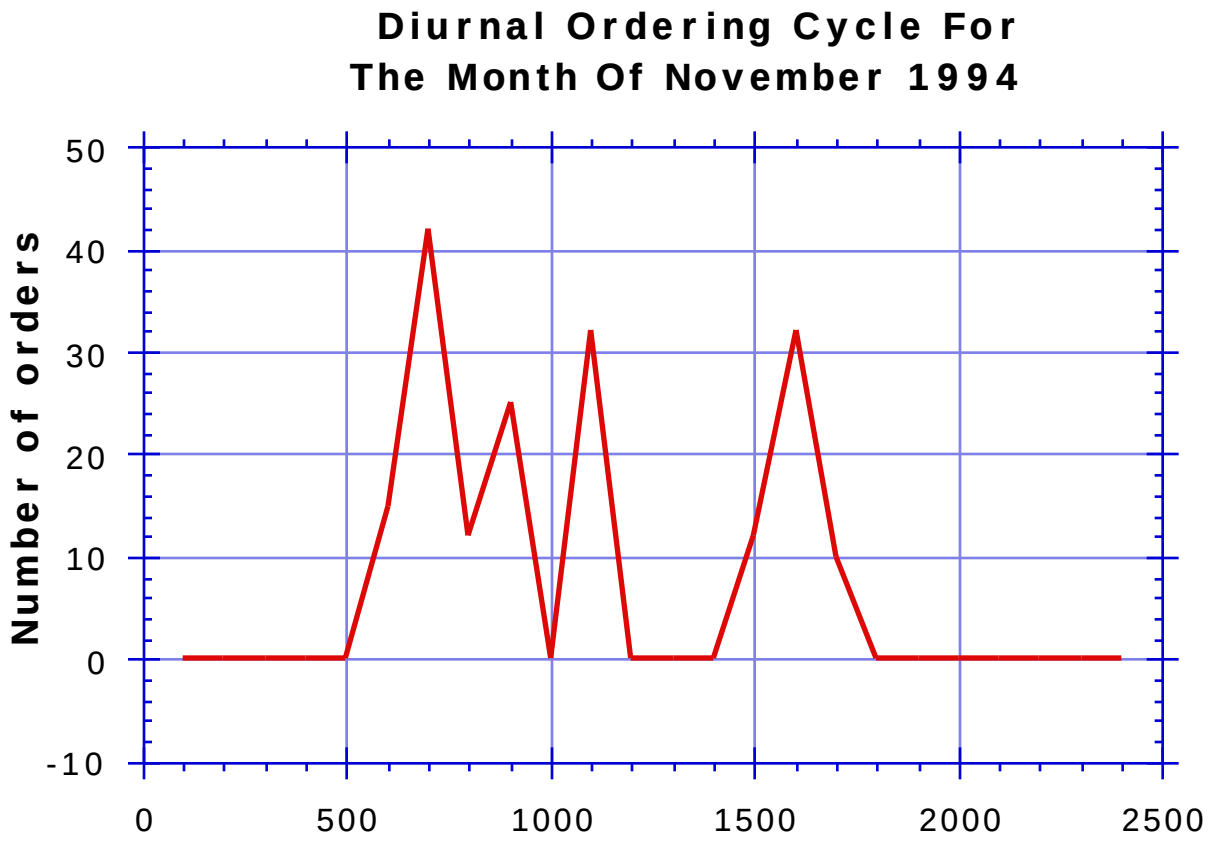

Fig. 17

Here again only the statistics average for the month of November, 1994 are plotted. It is obvious that there is no continuous stream of user requests but instead the users cluster about some specific periods. There is an early spurt of users at about 5-6 am local time which means that most of the requests are coming from the east coast. There is an interesting drop at about 8 am local time which likely reflects the 10 am coffee break in the east. The peak just before noon local time reflect the local users getting something ordered just before lunch. Lunch accounts for the zero level between 12 and 2 pm with the increase to a maximum at 4 pm corresponding to local and west coast users logging into the system. This emphasizes that we are all creatures of habit and that is true in how people use an online data system as well.

Discussion and Conclusions

Our Testbed has functioned well as a small scale analog of the EOSDIS. It has provided valuable insight into the ways people will use such an online data system for access to satellite data and software. The realization that such a system must provide analysis and application

software to use the data on the system is an important lesson learned.

Another very important lesson learned through this prototype was a recognition of the need to evolve the system in response to user needs. This is a fundamental tenant for the EOSDIS but it is difficult to realize just how such a system should evolve. Our Testbed is a good example of no matter how well one believes to have supplied a system of use to people there are user needs that have not been anticipated. Three of the four major changes in the Testbed system were motivated by user input. The last change was due to problems with the NCAR mass store which also makes it clear that a data system should not share computer or data storage resources.

We hope to continue the operation of the Testbed system as an end-to-end prototype of the future Version 1 (V1) EOSDIS. The present operation of Version 0 also serves as a very useful prototype but is difficult to change in response to user needs. Our more compact Testbed can be used to test various concepts planned for EOSDIS V1 in respect to how connected users will respond. We fully expect that by the release of V1 that our Testbed can be terminated and the services provided will be handled by the EOSDIS.

System Access

To gain access to navigate II, all users need to do is contact Tim Kelley (kelley@frodo.colorado.edu) or Jeff Anderson (andersoj@frodo.colorado.edu). The response to your email will be a copy of the "Quick Manual" and a sign-up sheet. The user must fill out the information in the sign-up sheet to gain access to the free data. Users will be given a password and be placed in the access files upon receipt of the sign-up sheet. Currently, users are allowed to navigate up to 5 days worth of AVHRR images in a 24 hour period. GOES images and program retrieval are currently set to an unlimited amount.

Within the next few months, navigate II will be accessesible from Mosaic and Netscape using the CCAR home page. All users will be notified of this option as well as a notification being placed on all of the current bulletin boards. New users will be asked to give information via an information dialog box window, be granted access to the system as a guest for the first order and then placed in the access files for subsequent orders.

Acknowledgements

This project was initially funded by the Advanced Information Science Research Program (AISRP) of the National Aeronautics and Space Administration (NASA). The authors would like to thank Glen Mucklow and Joe Bredekamp for their interest in this effort. The 1994 financial support of the system was provided by NASA Code YSC and we would

like to thank the program manager Martha Maiden for her interest in the system. Exabyte Corp. of Boulder, Colorado has been very helpful in providing storage systems at significantly reduced prices. We would also like to thank the many users of this system for their input and their patience.

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Fig. Caption

1. Initial EOSDIS Testbed hardware configuration. Located at NCAR the Mass Store and the Niwot computer are NCAR resources while Sanddunes and its hard drives are part of the Testbed system.

2. Navigate search window with city pop-up window.

3. Navigate system browse image which is a full AVHRR pass with a map overlay.

4. Navigate order window where the user specifies the information requested from the Testbed system.

5. Navigate system hardware configuration; again the Mass Store and the IBM RS/6000 Cluster are NCAR resources.

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